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### **SPECIFICATION**

#### **TITLE**

#### **MEDICAL SYSTEM WITH A MULTI-DOT ELECTRODE, WITH SUB-SIGNALS THEREFROM COMBINED INTO A SYNTHETIC REFERENCE**

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#### **BACKGROUND OF THE INVENTION**

##### **Field of the Invention**

The present invention relates to a medical system of the type employing a multi-dot electrode that interacts with a patient.

##### **Description of the Prior Art**

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Electrode bodies adapted for sensing and/or stimulating electrical activities of a heart and provided with a number of electrically insulated electrode surfaces at small distances from one another are known from United States Patent Nos. 6,064,905 and 4,848,352.

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In United States Patent No. 6,064,905 a multi-element tip electrode mapping catheter is known that has a tip section including a multi-element tip electrode mounted at the distal end of the tip section comprising a plurality of electrode members electrically isolated from one another and arranged such that, during use of the catheter within the heart, at least two different electrode members are capable of contacting the endocardium tissue at one time.

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United States Patent No. 4,848,352 relates to a method for cardiac pacing and sensing using combination of electrodes where a cardiac pacing lead is inserted into a heart chamber. The lead carries a plurality of separate electrodes positioned at the distal tip of the lead and electrically isolated from each other. A separate electrical conductor is provided for each electrode.

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The electrodes may e.g. be entered in an electrical conductive relation in order to allow sensing to take place from any or all of the electrodes.

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Signals detected e.g. inside a heart by a conventional heart electrode where the signal is detected either between two electrodes arranged at a distance from each other and close to the distal end (by using a. bipolar electrode) or between a single electrode inside the heart and an indifferent electrode arranged e.g. at the housing of the heart stimulator are often  
5 influenced by different kinds of interference. Normal interference signals may emanate from human body generated signals such as muscle interference or from unsuitable electromagnetic fields in the patient's environment.

The interference may be reduced by the use of a bipolar electrode  
10 system, where a short electrode distance is one reducing factor. This is a reason for using an electrode surface having several small dot electrodes.

However, experiments performed on animals have shown that the difference between the signals obtained from two dot electrodes at a multi-dot electrode unit is difficult to detect when using detectors conventionally used in  
15 heart stimulators. The reason is that the signals are too similar.

A conventional heart signal detector works on a pair of electrode surfaces and with traditional heart pacemaker signal processing. The traditional signal processing is amplification, band-pass filter and amplitude detection. The detector level relative the original signal amplitude is then most  
20 often between 0,5 mV up to 10 mV.

When sensing a heart signal with a lead having several small electrodes close to each other, e.g. in a multi-dot electrode unit, there may be a problem to detect the signal if conventional pacemaker signal processing is used because the differential signal may be only a small part of the total  
25 signal amplitude. This part of the amplitude may be in the order 0,1 to 1 mV and can often be less than 0,1 mV.

Depending on the vector of the heart activity propagation in relation to the electrode surfaces, the differential signal can even be reduced to nearly

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zero. Due to the fact that the propagation vector of heart activity varies, the differential signal amplitude also varies.

5 One way to optimize signal detection would be to monitor all combinations of electrode pairs and momentarily select the pair with highest amplitude or at least avoid the pair with zero amplitude. As the propagation vector of heart activity continuously varies, the monitoring and optimization process must be continuously ongoing which is considered difficult to implement.

## **SUMMARY OF THE INVENTION**

10 An object of the present invention is to address the above-stated problem regarding detection when using small electrodes arranged at a small distance from one another, e.g. when using a multi-dot electrode unit.

The above object is achieved in accordance with the present invention in a medical system for detecting heart events, including an electrode lead  
15 provided with a multi-dot electrode that has at least three dot electrodes, the multi-dot electrode being adapted for intracorporeal sensing of heart signals, wherein the heart signals sensed by the respective dot electrodes are supplied to a processor wherein the signals are combined and a synthetic reference signal is determined, and the difference between each dot electrode  
20 signal and the synthetic reference is determined, and an indication signal is formed based on the respective differences, the indication signal being used to detect heart events.

The synthetic reference signal can be a synthetic reference voltage.

25 Thus, the above object is achieved by creating a synthetic reference signal from all or at least three of the dot electrodes to which the sensed signal from each of the electrodes may be related.

According to the present invention the amplitudes of all (or most of) the dot electrodes are combined to a synthetic reference signal. The only

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requirement for the signal processing is that there is some difference between any of the dot electrode pairs. As all dot electrodes are grouped together, external interference is totally avoided and high amplification for the differential signal may be used.

- 5           The processor that processes the detected signals may be arranged either close to the multi-dot electrode unit (e.g. in the electrode lead tip) or e.g. in a heart stimulator to which the electrode lead is connected.

- 10           The signal between the synthetic reference signal and any electrode thus will have a significant amplitude, as the amplitude of the heart signal not can be totally cancelled. The requirement of the electrodes used to create the synthetic reference signal is that not two pairs of electrodes have the same vectors.

- 15           This results in a signal separated from zero between any of the electrodes and the synthetic reference signal, and that each signal in relation to the synthetic reference signal will have enough amplitude to contribute for detection and the cancellation phenomenon in bipolar systems, i.e. two dots, is thereby avoided.

- 20           The signal processing performed by the processor is simple and straightforward. There is no need to filter the signals and the unsuitable side effects of the pacemaker filters (may be referred to as "memory-effects" of the filter) used today are avoided.

The present invention accomplishes total avoidance of some of the signal problems in pacemakers as signal detection of different types of interference such as external interference or far field heart signals.

- 25           In a preferred embodiment of the present invention an electrode lead is provided with the multi-dot electrode unit and a processing means arranged close to the multi-dot electrode unit and supplies detection signal(s) from the processing means through the lead into the heart stimulator.

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### **DESCRIPTION OF THE DRAWINGS**

Figure 1 shows a block diagram of the medical system according to a preferred embodiment of the present invention.

5 Figure 2 shows a block diagram that schematically illustrates the multi-dot electrode unit and the processing means according to the preferred embodiment.

Figure 3 shows a diagram of a preferred embodiment as a schematic of electronics of the present invention.

10 Figure 4 is a cut through view of a multi-dot electrode unit in the distal tip of an electrode lead.

Figure 5 is a cross-sectional view of the multi-dot electrode unit in the distal tip of an electrode lead as shown in figure 4.

Figure 6 shows signal recordings from seven dot electrodes of a multi-dot electrode unit placed in the ventricle of an animal.

15 Figure 7 shows a small part of the signal recordings as in figure 6 in a larger scale.

Figure 8 shows differences of signal recordings of seven dot electrodes (S1-S7) of a multi-dot electrode unit where electrode S1 is used as a reference.

20 Figure 9 shows differences of signal recordings of seven dot electrodes (S1-S7) of a multi-dot electrode unit where the synthetic reference signal (SR) calculated according to the present invention is used as a reference.

Figure 10 shows, three signal tracings of different processed signals.

25 Figure 11 shows the same signals as in figure 10 but with another time scale.

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### DESCRIPTION OF THE PREFERRED EMBODIMENTS

A multi-dot electrode unit used in connection with the present invention is preferably arranged at the distal end of an electrode lead. The multi-dot electrode unit includes a plurality of dot electrodes electrically insulated from one another and arranged at small distances from one another. An exemplary distance between dot electrodes is less than 1 mm.

In its broadest aspect a dot electrode should be regarded as a small electrode surface having an optional geometric shape, e.g. circular, elliptical, rectangular, square, band-shaped etc. In case of a circular dot electrode the diameter is in the interval of 0.05 to 1mm. The distance between adjacent dot electrode surfaces is preferably less than 1 mm. The distance between the most distant dot electrodes in a multi-dot electrode unit is less than 10 mm.

The electrode lead provided with the multi-dot electrode unit will be able to pick up nearly the same electrical signal on each dot electrode.

In order to perform bipolar sensing using the dot electrodes the differential signal (that is the signal between two dot electrodes) is small and a special effort must be taken in the design to avoid so-called common mode effects.

Initially a general overview of the present invention will be given.

According to the present invention the signals from N dot electrodes are added together in order to create an un-normalized synthetic reference signal. N could be any number between 3 and the total number of dot electrodes. The total number of dot electrodes may be very large but a suitable number is between 10 and 30, preferably 20. In one embodiment N is in the range 4-8. The created signal is then divided by N and a normalized synthetic reference signal is obtained. The differential signal to be used for detection is made in relation to the normalized synthetic reference signal.

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The following example further illustrates how the synthetic reference signal is created and how a differential signal for a specific dot electrode in relation to the created synthetic reference signal is determined. The signal amplitude at a dot electrode "i" is designated  $U_i$  in relation to a reference. This  
5 reference may be obtained from a point capable of providing a long-term stable reference level, e.g. a separate indifferent electrode at the pacemaker housing or the battery in the pacemaker. The un-normalized synthetic reference signal will then be:

$$\sum (U_1 + \dots + U_N)$$

10 A normalized synthetic reference signal (SR-signal) will then be:

$$\text{SR-signal} = (1/N) \times \sum (U_1 + \dots + U_N)$$

The differential signal  $A_{\text{diff}(i)}$  for dot electrode i will then be:

$$A_{\text{diff}(i)} = U_i - (1/N) \times \sum (U_1 + \dots + U_N)$$

15 This differential signal is amplified to a suitable detecting level. As the short distance between the dot electrodes essentially reduces the influence of interference the only filtering necessary to perform is to transfer the signal shape to a shape that is easy to detect.

To detect the heart signal from activity near the dot electrodes the contribution from all electrodes is most optimal. As the difference signal of  
20 each dot electrode relative the synthetic reference can be both positive and negative the difference signals must be processed prior the signals are combined.

According to a preferred embodiment of the present invention the absolute values of the difference signals are determined and then added  
25 together to form an indication signal. This sign conversion may be achieved by rectification. Alternatively and according to an alternative embodiment, the

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difference signals instead are squared and then added together to form the indication signal.

Still a further possibility is to form a value representing the signal contents for the difference signals upon which the indication signal is formed.

5           According to a preferred embodiment of the present invention the signal processor is arranged close to the multi-dot electrode unit. As indicated above the multi-dot electrode unit preferably is placed at the distal tip of the electrode lead. However, any position along the electrode lead may be possible without departing from the scope of the present invention as it is  
10       defined in the appended claims.

Thus, according to this preferred embodiment the processing means includes a specific amplifier and detector circuit placed close to the electrode tip. In this case a fully integrated circuitry with enough small size to be placed within one or a few cubic millimeters arranged in the electrode tip.

15           For power supply to the processor two conductors are arranged in the electrode lead from the heart stimulator (that includes a battery) to the electrode tip. One of the conductors may be the one used for heart stimulation. The information from the signal detection may also be sent from the electrode tip to the heart stimulator on the same pair of conductors. By  
20       using switched loading an altered voltage level may transfer information in binary format from the electrode tip into the heart pacemaker. The signal transfer does not contain complete information with regard to full signal morphology but only detection information is transferred. The detection information may then be used by a control unit in the heart stimulator to  
25       control e.g. the pulse generation.

The signal processing performed by the processing means to detect heart activity may be done in several ways, for example band pass filtering of the signals, adding signals, correlate signals together etc.



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The type of electronics can be of several types, e.g. traditional analogue, analogue to digital converted and then digitally processed, analogue sampled and processed in analogue way by a so-called switch capacitor technique. Thus, the present invention may be implemented in  
5 many different ways where some will be described in the following.

The preferred implementation of the processor, technical realization as micro-power electronics with the smallest dimensions to be assembled into the electrode tip, is the so-called sampled switch cap technique. However, for easier understanding of this implementation the description proceeds as  
10 traditional analog technique, keeping in mind that there are methods for direct translation between those techniques.

Figure 1 shows a block diagram of the medical system according to a preferred embodiment of the present invention. The system has an electrode lead 2 provided with a multi-dot electrode unit 4 including a processor 6. The  
15 multi-dot electrode unit 4 is provided with a number of dot electrodes 8 and may be arranged near or in contact with a heart wall, e.g. in the right ventricle of the heart. In the figure the multi-dot electrode unit is arranged close to the distal end of the electrode lead, i.e. in the electrode lead tip, but may also be arranged at another position along the lead, e.g. within the form of a  
20 cylindrical ring electrode at a predetermined distance from the distal end. The electrode lead 2 is coupled to an implantable heart stimulator 10 that inter alia includes a heart therapy and control unit 12 and a power supply 14.

Figure 2 shows a block diagram that schematically illustrates the multi-dot electrode unit and the processing means according to the preferred  
25 embodiment. Each of the dot electrodes  $8_1-8_N$  is connected to a respective amplifier  $16_1-16_N$  in order to amplify the dot electrode signals sensed by the dot electrodes.

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The signal ( $U_1 - U_N$ ) provided to each amplifier 16 must be in relation to any reference voltage. The reference voltage could be any stable voltage potential such as the power supply voltage or a derivate of such voltage.

If the amplitude of a sensed dot electrode signal is in the order of 0.1 to 2 mV the amplification should be in the range of 50-2000 in order to obtain a dynamic detection voltage in the order of 1 Volt. The amplifying means are connected to a synthetic reference calculation means 18 where a synthetic reference signal (SR-signal) is calculated. The synthetic reference signal and the amplified dot electrode signals are applied to difference signal means 20<sub>1</sub>-20<sub>N</sub> where differences between each of the amplified dot electrode signals and the synthetic reference signal are formed according to the formula  $A_{diff(i)} = U_i - \text{SR-signal}$ , where  $i = 1 \dots N$ .

According to a preferred embodiment of the present invention the difference signals are applied to rectifiers 22<sub>1</sub>-22<sub>N</sub> where the signals are rectified and these rectified signals are in turn applied to a summing unit 24. The summing unit determines an indication signal that is applied to a detector 26 provided with predetermined heart event detection criteria that may include one or many threshold(s) representing different predetermined heart events to be detected. One or many detection signals is(are) generated by the detector 26 as a result of the these comparisons.

The multi-dot electrode unit is in particular suitable for detecting "fast" heart events in the close vicinity of the electrode. If the multi-dot electrode unit is placed in the atrium these fast heart events could be spontaneous or stimulated P-waves and atrial fibrillation or flutter and if the electrode is placed in the ventricle spontaneous or stimulated R-waves could be detected.

According to an alternative embodiment of the present invention the processing means is arranged at a distance from the multi-dot electrode unit, e.g. inside the body in an implantable heart stimulator or outside the body in an external medical device. In this alternative embodiment each dot electrode

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is connected via a separate conductor in the electrode lead to the processing means located e.g. inside a heart stimulator housing.

Figure 3 shows a diagram as a schematic of electronics illustrating the circuitry of the preferred embodiment of the present invention. In the illustrated embodiment three of the N dot electrodes are shown. The rectangles represent resistors having the resistance R except where indicated a resistor value of R/N and the triangles represent operational amplifiers.

$U_1 - U_N$  are the dot electrode potentials in relation to an electrical reference point. In Figure 3  $U_G$  represents a ground potential against which each of the dot electrode potentials are related to. It should be noted that  $U_G$  is a conducting surface (e.g. a metal surface) close to the multi-dot electrodes (e.g. inside said processing means). This potential ( $U_G$ ) is not stable compared to e.g. a dot electrode since it is related to the battery source and the housing of the implant. However, if this defined ground potential ( $U_G$ ) or zero potential is used internally in the processing means as the earth potential then no additional disturbance or interference is induced during the further processing of the signals.

Using the same reference signs as in figure 2 the circuitry in figure 3 includes the amplifying means 16 that amplify the sensed heart signals and generate dot electrode signals ( $U_1 - U_N$ ), the synthetic reference calculation unit 18 that calculates the synthetic reference signal (SR-signal) and the difference signal unit 20 that determines the difference signals  $A_{\text{diff}(1)} - A_{\text{diff}(N)}$ .

Figure 4 is a cut through view of a multi-dot electrode unit in the distal tip of an electrode lead with processing means 6 and two conductors 32 connecting the processor to the control unit in the pacemaker. The distal tip is a hermetic capsule of ceramic material with a cavity 34 housing the processing means. The diameter of the capsule is in the order of 3 mm. The two conductors pass through the wall of the capsule where it is connected to

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the processing means via wire bonding 36. The dot electrodes 8 are evenly spread on the end of the electrode tip and are connected to the processing means.

5 Figure 5 is a cross-sectional view of the multi-dot electrode unit in the distal tip of an electrode lead as shown in figure 4. The cavity 34 is closed with a lid 38 inserted from above and hermetically sealed to the capsule. The sealing may be formed by a low temperature melting glass or some type of metallic soldering.

10 Figure 6 shows signal recordings from seven dot electrodes of a multi-dot electrode unit placed in the ventricle of an animal where the R-waves easily may be identified. The signals are unipolar which means that they are measured between each of the electrodes and an electrode surface at the capsule of the pacemaker. The time scale (horizontal axis) is from 0 to 3 seconds. The signal from electrode 7 is at the top and electrode 1 at the  
15 bottom. Only small non-obvious differences between the electrode signals may be identified.

Figure 7 shows a small part of the signal recordings as in figure 6 in a larger scale (0.105 to 0.130 seconds). Also here only small differences may be identified.

20 Figure 8 shows differences of signal recordings of seven dot electrodes (S1-S7) of a multi-dot electrode unit where electrode S1 is used as a reference. The time scale is 0.105 to 0.130 seconds. The signal S6-S1 is cancelled out because the signals S6 and S1 are too similar. Investigations have shown as a rule that one or two of the bipolar signals are cancelled out.  
25 Which pair that is cancelled out cannot be predicted. Even if one pair is good and another is bad the situation may be the opposite due to varying conditions such as varying propagation vector or activity. This illustrates that the use of one bipolar signal from the multi-dot electrode unit is not sufficient and if more bipolar signals than one are used selection problems may occur.

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Figure 9 shows differences of signal recordings of seven dot electrodes (S1-S7) of a multi-dot electrode unit where the synthetic reference signal (SR) calculated according to the present invention is used as a reference. The time scale is 0.105 to 0.130 seconds. The signals S1 to S7 are unipolar R-wave signals from the multi-dot electrode unit placed in the right ventricle of an animal using the indifferent electrode at the housing as reference. The signal at the bottom is the average of the signals, i.e. the synthetic reference signal. These signal differences (S1-SR, ... ,S7-SR) illustrate that there is a low but significant signal amplitude in all signal recordings.

Figure 10 shows three signal tracings of different processed signals. The signal at the top show the average of absolute value of difference signals processed according to the whole processing chain as earlier described according to the invention, i.e. all the signal differences created with use of the synthetic reference (S1-SR, ... ,S7-SR) are rectified and then added together. The heart activity is easy to detect, as the pulse amplitude is very distinguished. Detection occurs when the pulse amplitude is higher than a preset detection amplitude threshold (not shown).

The second signal (in the middle) shown in figure 10 is included to show that other signal processing also may be used to get a detectable signal result from all the electrode signals, in this case the average of the absolute amplitude values of all unipolar signals. However, the signal processing used according to the present invention achieves a more distinguished result, which has superior detection qualities.

The signal at the bottom of figure 10 is the average of the dot electrode potentials, i.e. the synthetic reference signal (SR).

Figure 11 shows the same signals as in figure 10 but with another time scale (0,105 to 0,130 seconds). As in figure 10 the signal at the top in the figure illustrates the use of a signal processing according to the present invention. Investigations have shown that this signal shape has less variation

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than the variation in signal shape of each dot electrode signal, and also less variation than the variations of the average signal.

Although modifications and changes may be suggested by those skilled in the art, it is the invention of the inventor to embody within the patent  
5 warranted hereon all changes and modifications as reasonably and properly come within the scope of his contribution to the art.